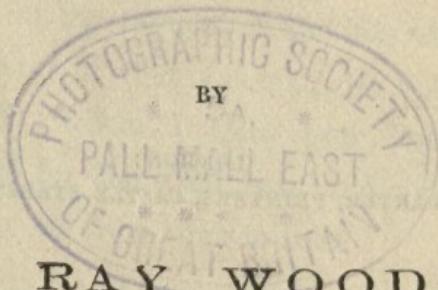


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THE
SPECTROSCOPE

AND

ITS RELATION TO PHOTOGRAPHY.



C. RAY WOODS.

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PREFACE.

THE following pages consist of a series of articles written for photographers, and published in the columns of the PHOTOGRAPHIC NEWS. They were undertaken at the request of the late esteemed Editor and Proprietor of that Journal, H. Baden Pritchard, Esq., F.C.S., whom I shall ever hold in grateful remembrance for the kind help and valuable suggestions he gave me from time to time.

I also take this opportunity of publicly expressing my thanks to Captain Abney, R.E., F.R.S., and J. Norman Lockyer, Esq., F.R.S., in whose laboratories much of the information contained in the following pages was gleaned.

C. RAY WOODS.

Hornsey Rise, January, 1885.



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THE SPECTROSCOPE.

INTRODUCTION.

IN the early part of the present century, when Wedgewood, Niépce, and others were making some of the earliest attempts at producing pictures by the aid of the sun, a new method of investigating the nature and properties of light was brought about by the use of a triangular glass prism combined with a narrow slit. Spectroscopy and photography may almost be regarded as twin sciences, for though the former was the first to assume a really practical shape, the births of the two sciences were contemporaneous, and from that time to the present many of those experimenters who have given their attention to the one have been equally ardent disciples of the other. Both studies have been mutually dependent on one another, and it would be exceedingly difficult to say which is the greater debtor ; if photography has had to go to the spectroscope for explanations and revelations concerning many of its obscure points, the spectroscope is, in its turn, no less indebted to photography for its recording power, so much more trustworthy than human vision.

Either science might have progressed independently of the other, but, happily, such misfortune was rendered impossible by the facility with which men, almost intuitively, perceived the relationship.

This partial independence of two branches of science, both dependent on one common phenomenon—light—is, unfortunately, however, the reason why some at least of the votaries of the one pay but little attention to the other. Photographers, it must be admitted, are the worst sinners in this respect, nor can it be wondered at, considering that their science has assumed a commercial aspect, and has thus become an art. The wonder is, after all, that so many photographers follow with interest the accounts continually being published about spectroscopic work. And yet, except when these accounts are chiefly intended for photographers, and occasionally even then, they are necessarily somewhat technical, and correspondingly difficult to be understood by those who do not make spectroscopy a special study.

That a large number of workers do not interest themselves in such matters is, under the circumstances, scarcely a matter for surprise. It is for this class that the writer proposes to give a short series of articles on the "Spectroscope and its Relation to Photography." Whilst endeavouring to make the subject clear, it is proposed neither to write a comprehensive treatise for those already interested in the subject, nor yet an extensively elementary account for that much-catered-for entity, "the meanest understanding."

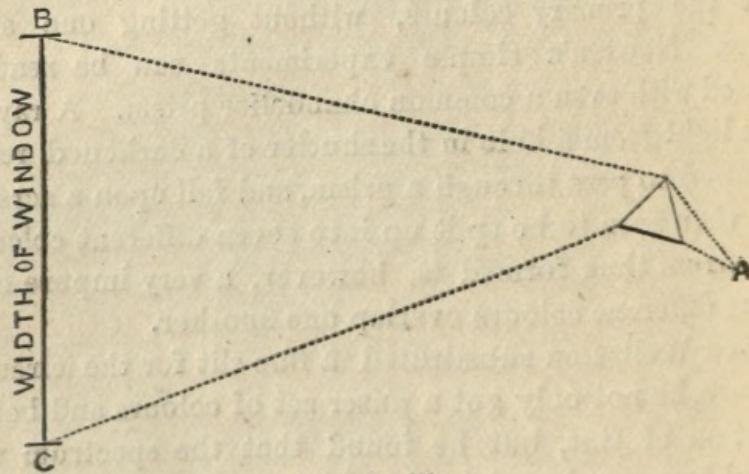
The individual of fairy legend and folk-lore, who went to sleep for a hundred years or so, seems to have a counterpart in the annals of science. The "sleeping beauty," which, under the hand of Newton, bid fair to arise and

astonish and attract the world, was scarcely even unveiled till the touch of Wollaston roused the dormant power, and brought it into a world of life. Why Newton failed to discover the spectroscope the reader knows; he used at first a round hole, and then a wide instead of a narrow slit, and for a century and a quarter the man of science went on repeating the experiment, and the artist glibly talked about the primary colours, without getting one step further. Newton's simple experiments can be readily repeated with even a common chandelier prism. A ray of white light from a hole in the shutter of a darkened room is allowed to pass through a prism, and fall upon a screen. It is then seen to be split up into seven different colours. A spectrum thus formed is, however, a very impure one, for the different colours overlap one another.

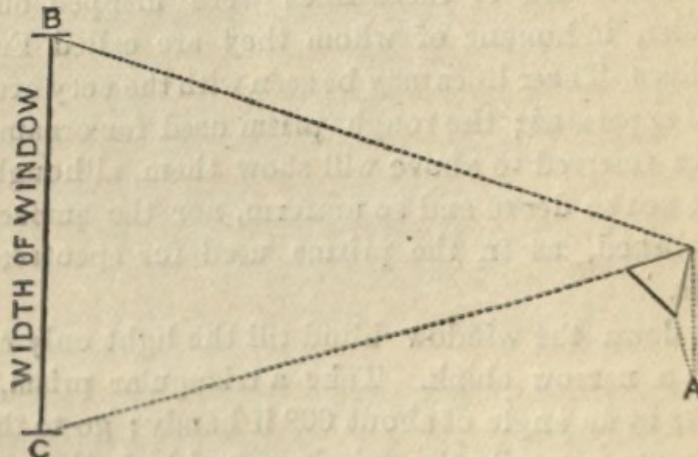
When Wollaston substituted a fine slit for the circular aperture, he not only got a purer set of colours and better gradation of tint, but he found that the spectrum was crossed by a number of fine black lines. Only twelve years elapsed before 576 of these lines were mapped out by Fraunhofer, in honour of whom they are called Fraunhoferic lines. These lines may be seen with the very crudest piece of apparatus; the rough prism used for ornamental purposes referred to above will show them, although the glass is not so dense and so uniform, nor the surfaces as well polished, as in the prisms used for spectroscopic purposes.

Draw down the window blind till the light only comes through a narrow chink. Take a triangular prism, with two sides at an angle of about 60° if handy; go to the end of the room opposite the window, and look through the prism, holding it in a horizontal position. Some of the darker lines of the solar spectrum may then be seen.

Another way of seeing these lines, and one which may be new even to many of those familiar with the subject, is to use, not a narrow chink, but a hole of any shape, or even the whole aperture of the window. Standing at the further end of the room, and holding the prism vertically, get the eye and the prism into such a position that the whole of the window is seen.



First Position.



Second Position.

Fig. 1.

The accompanying diagram (fig. 1, first position) gives

the relative positions of window, prism, and observer, A being the position of the observer's eye, and B C representing the width of the window, the sides of the framework of which will appear fringed with colour.

Now turn the prism round till one edge is nearly at right angles to the window, slightly shifting the position of the eye at the same time (fig. 1, second position). As the position of the prism is altered, the window will appear gradually to contract till the spectra at its opposite sides meet, when the dark lines will appear.

As mentioned, a prism of ordinary glass is quite sufficient for the purpose ; in fact, with very dense glass, the effect is not so readily obtained. If the observer, instead of using an aperture such as a window or doorway, looks at the sun in this manner, he will be able to see a very large number of lines, and this, remember, without the aid of a slit. As the reader will see, what takes place is, practically speaking, of the nature of foreshortening.

But to return : Fraunhofer, in A.D. 1814, mapped 576 lines of the solar spectrum, his apparatus consisting only of a slit and a prism. A further addition was made by a famous optician, Mr. Simms, who added what is known as the collimator and telescope. The first consists of a lens placed in front of the telescope, and so arranged that the slit is in its focus. The utility of this will be at once apparent, for all light passing through the slit and falling upon the lens is rendered parallel, and is thus utilized, instead of the small amount of parallel rays that pass through a fine slit. The object of the telescope is to collect these rays and pass them all through the small aperture of the pupil of the eye. The principle of the telescope here is the same as in viewing a distant object—a landscape or a celestial sphere. The object-glass of the

telescope brings the rays to a focus, and forms an image of the spectrum. This image the spectrum photographer receives upon his plate ; the observer adds the eye-piece of the telescope, and magnifies it. This is still the usual form of spectroscope, and in the next chapter will be shown in detail the construction of such an instrument suited to the requirements of a photographer, and the adjustments necessary in order to obtain the best results that the apparatus will give.

CHAPTER I.

THE PARTS AND ADJUSTMENTS OF THE INSTRUMENT.

To say that the prism is the most important part of the instrument is almost superfluous. The essential properties of this part of the apparatus are as follow:—Clearness and freedom from inequalities in the structure of the glass, high dispersive power, and accurately plane and well-polished surfaces. Ordinary crown glass is not available, as it does not possess sufficient dispersive power—or, in other words, it does not widen out the spectrum to the most desirable extent. Flint glass is that generally used, and is to be obtained of different densities according to the purpose for which it is required. For photographic purposes, a clear, white quality is the best; and though this has not the dispersive powers of the densest kind, it is as well to sacrifice a little dispersion to purity of colour, the denser glass having an objectionable yellow hue in addition to a liability to tarnish.

Various other media are frequently used for spectroscopic work, such as quartz and Iceland spar, which are

often required for special purposes, such as photographing the extreme ultra-violet rays.

Some liquids, such as bi-sulphide of carbon, and certain dense organic compounds, are also brought into requisition; but they are useful mainly for lecture demonstrations. Slight changes in temperature will cause such variations in density throughout a bisulphide of carbon prism, for instance, as to render it useless for fine work.

The principles of optics which give to a prism its chief value as an aid to scientific research are too well known to photographers to need more than a brief glance. When a ray of light passes at an angle from one medium to another of different density, it is refracted, or bent out of its course. A very good illustration of this—but one that is not to be found in the popular text-books—has been given in what takes place when a body of men marching across a piece of solid ground come to a piece of boggy soil, the boundary of which is not perpendicular to their path. Those who reach the bog first find their movements impeded, and their comrades in the front rank who are still on solid ground get a little in advance. As a natural consequence, when both sides of the rank find themselves in the bog, it is found that their course has been more or less altered. The refraction or bending of a light wave in passing, say, from air to glass is similar to this: “That end of the wave which first reaches the medium will be the first retarded by it, the other portions, as they enter the glass, being retarded in succession.”* If the sides of the glass are parallel, an equal amount of bending in an opposite direction takes place, and the ray passes out along a path parallel to that at which it first enters the

* Tyndall on “Light.”

glass. If the sides are not parallel, as in the case of a prism, yet another path is followed.

But in the passage of a ray of light composed of waves which have not all the same length, something else takes place. The ray of white light is split up into its many constituents, that light composed of the longest waves being less bent out of its course than the light of shorter wave length. This is shown in the subjoined diagram:

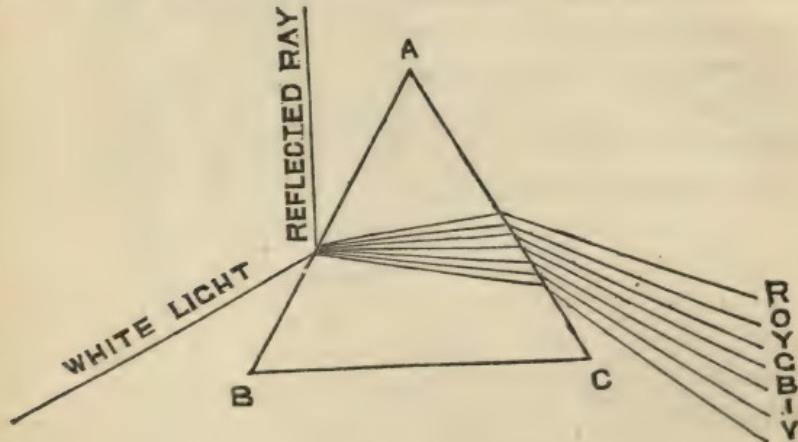


Fig. 2.

A ray of white light strikes the prism at an angle; part of it is reflected, and the remainder passes into the prism and is split up into its several constituents, these different rays being still more spread out on emerging into the air. The violet rays, on account of their shorter wave length, are most refracted, and are therefore called the most refrangible rays of the visible spectrum, the red rays, which are least bent out of their course, being called the least refrangible. Between these come those rays which produce on the retina of the eye the sensations of indigo or dark blue, blue, green, yellow, and orange. At each end of the visible spectrum are rays which are invisible to the eye,

and, as will be shown in subsequent articles, have to have their presence made known by other means.

It will be convenient here to mention, incidentally, a little difficulty that the reader may meet with.

Figure 2 practically shows Newton's experiment of passing a beam of sunlight through a prism, and letting it (the light) fall upon a screen, the violet rays emerging from that part of the prism nearest the base (BC), and the red from a part nearest the apex (A). But if the reader employs his eye instead of a screen, as in the experiments detailed in the previous article, he will notice that the reverse of this seems to take place, and the red appears nearest the base. The following diagram will explain this apparent anomaly.

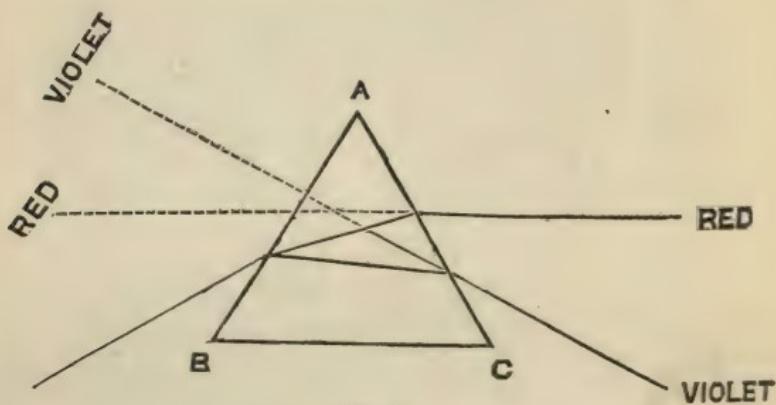


Fig. 3.

The direction of the red and violet rays is shown as in fig. 2, but the experimenter sees, not the band of colour formed by the rays as they fall upon the screen, but the slit itself, displaced and elongated into a band of colour. The dotted lines give the apparent positions of the slit as shown by the red and violet rays.

Next in importance to the prism comes the slit, for on

the trueness of this piece of apparatus a great deal of the beauty of definition of a spectroscope depends. The slit plate is usually constructed of brass, the slit itself being formed by two pieces of metal, one of which is mounted in a groove, so that the slit can be opened and closed at pleasure. The edges forming the slit are ground down like a thin wedge, and these edges must be perfectly straight and smooth in addition to being parallel. In the best instruments the edges themselves are formed of a hard alloy of platinum and iridium, and their distances apart are regulated by a screw, to which is attached a circle and vernier to read off the width of the opening. It is as easy to mentally picture a perfect slit as it is to define a straight line, but the practical accomplishment of the former is almost as difficult as the latter. The slightest inequality in the slit, even that caused by a few specks of dust, will show itself. Before commencing work, it is advisable to open the slit, and clean the jaws with a piece of soft wood, such as a lucifer match cut to a point. Where great delicacy is not essential, a slit may be formed by attaching a piece of tinfoil to a piece of glass, and cutting through the tinfoil with a sharp knife or razor.

For the collimator and telescope, achromatic lenses are not essential, though desirable. Lenses of about eight to ten inches in focal length will be found most suitable for a single prism spectroscope. The slit should be placed in the focus of the collimating lens; the right place is most readily found by turning the tube, to which are attached the collimating lens and slit, towards the sun, holding a slip of paper between the jaws of the widely-opened slit, and focussing the image of the sun upon it. Absolute accuracy is not essential. The collimating lens should be large enough to fill the prism, and the lens of the camera,

or the object-glass of the telescope (they both amount to the same thing), should be large enough to take in all the light coming from the prism. It is scarcely necessary to mention that the eye-piece of the telescope should possess an arrangement for focussing. The focus varies considerably for different rays, as the photographer will find, especially if he uses non-achromatic lenses, and he must use a very considerable amount of swing-back to get all the rays in focus at one and the same time. Fig. 4 is a

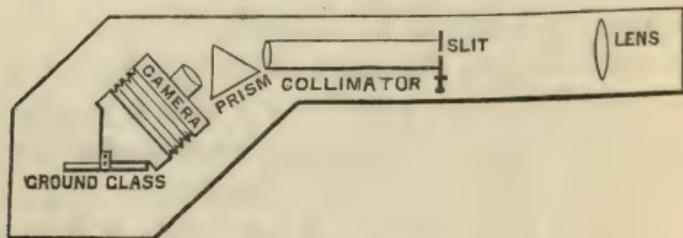


Fig. 4.

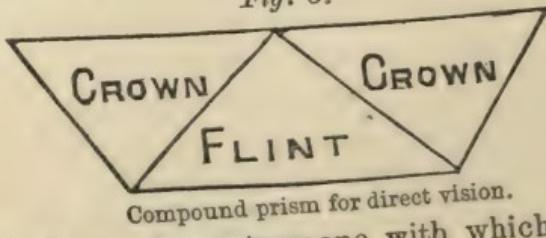
diagrammatic illustration of a spectroscope used for photographing the corona in 1882, and the amount of swing-back represented there was scarcely more than was required for all the rays from ultra-violet to infra-red. The same diagram shows the relative positions of the slit, collimator, prism, and camera. In the instrument referred to, the rest of the apparatus was constructed of wood. The photographer may readily convert his camera and lens into a temporary telescope for eye observations by turning aside the ground glass, and holding his magnifier in its place.

It only remains now to describe the adjustment of the prism, relative to collimator and camera. The prism, in order to get the best results, must be adjusted for what is called "minimum deviation," that is, it should be in such a position that the ray leaves the prism at the same

angle at which it enters it. The following is an easy method :—

A source of light is placed near the slit, before the camera or telescope is put into position, and the observer then looks at the slit through the prism. The prism is then slowly turned round. By moving it in one direction the spectrum will move, as it were, towards that side which the violet is nearest to, till at last it moves right out of the field of vision. If the prism is then revolved in an opposite direction, the spectrum will again come into view, and appear to move more and more towards the red till it comes to a standstill ; by continuing the same motion the spectrum will then move back again. At the point of rest is the proper position, when the prism will be, roughly, at the angle of minimum deviation. A glance at fig. 2 will, however, show that this angle is not the same for each ray. The photographer will, therefore, watch more particularly the blue rays, and leave his prism where those rays appear stationary. When there is more than one prism, the first one is adjusted, then the second is added, and so on, till they are all in position. It is usual, however, for spectrosopes to possess a mechanical arrangement by which all the prisms are adjusted at once. The camera may then be put in position, and the spectrum focussed on the ground glass.

Fig. 5.



Compound prism for direct vision.

A handy form of spectroscope with which the photographer is familiar, one suited for eye observations such

as examining the light that passes through a particular kind of glass, is the direct vision spectroscope, the construction of the prism of which is shown on page 13.

By the use of a combination of flint and crown glass, the rays are made to follow a straight path, whilst some of the dispersion is retained. The action is just the reverse of that of an achromatic lens, in which the colours of the spectrum are done away with, whilst the deviation is retained.

CHAPTER II.

THE SPECTRUM.

WE are now in a position to make ourselves acquainted with the spectrum, and to consider a few of the properties of light on which the spectroscope is able to impart information ; but it is absolutely necessary, first of all, that we should make ourselves familiar with the different parts of this rainbow-coloured band, before we can properly attempt to define any of the points bearing on the familiar operations of the laboratory and dark-room. It is not needful to study the spectrum too minutely ; it will be sufficient to become acquainted with certain defined landmarks by which it will be possible more or less accurately to point to any particular part of the spectrum.

We have some such index in the colours of the spectrum, but that alone is not sufficient. To say that such and such a thing takes place at the blue end, for instance, is vague, and may or may not convey an idea with scientific precision. Nor is that all. All eyes are not the same, and apart from definite colour-blindness, two persons may not gather the same mental impression from looking at a particular part of the spectrum. Again, the condition of

the eye is not always the same, for by using the eye to some particular colour for a time, it is easy to produce a partial and temporary colour-blindness, to make the retina less sensitive to certain rays. The reader will see this more clearly, perhaps, by a few illustrations from actual experience with the spectroscope. Ask two observers, for instance, where the green and blue parts of the spectrum appear to blend ; they will seldom mark the same place. Again, look with the spectroscope towards a dull part of the sky, then to a bright portion, and lastly to the sun itself. At each change in the intensity of the light, the colours of the spectrum will appear to have shifted their position in reference to the dark solar lines. The change in position may be small, but it will be enough to show how inefficient the sensation of colour is to define accurately any given part of the spectrum. This has been very well put by the Astronomer-Royal for Scotland, who says : "The colours, unfortunately, are not, indeed, so absolutely constant in spectrum place as are the Fraunhoferic lines ; for they (the colours) seem to be endowed with certain extents of locomotion in the spectrum according to the brightness of the light at the time, and the state of the eye. But still these ranges of locomotion never change the appearance of a colour from one side of the spectrum to the other, but only produce certain small variations of + or - on the standard colour at, and for, that place."*

The colour sensation caused by a particular ray cannot, therefore, be relied upon to furnish more than a *general* indication of its position ; but as a rough guide it is sufficiently useful, and will be frequently used in these pages. To begin with, it would be almost impossible to

* Piazzi Smyth, "Madeira Spectroscopic."

indicate where and how the reader will recognize the principal Fraunhoferic lines without some such guide. Turn the spectroscope, then, to a bright portion of the sky, using a magnifier in place of the ground glass if the camera is being used. For the central parts of the spectrum this light will be quite bright enough, and will not tire the eyes; but for the rays in the dark blue and violet, and for the extreme red end, the direct light of the sun may be required. If more convenient, a small mirror or piece of looking-glass may be used to throw the light into the slit of the instrument placed horizontally instead of pointing it to the sun or sky.

The line that can be most unmistakably recognized is the line called D in the yellow. This line is seen really to consist of two when viewed under higher dispersion. Looking from D towards the red, another well-marked dark line is noticed, called C; still lower in the red, and if the instrument is

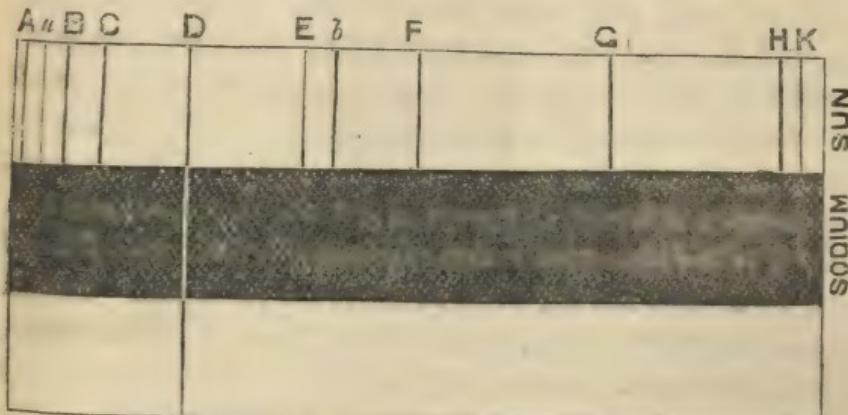


Fig. 6.

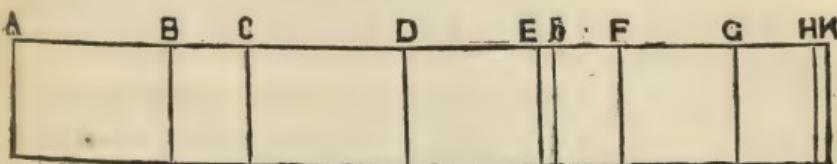
turned only towards the sky almost at the extreme part of the red end of the visible spectrum, is B. If the spectroscope be pointed to the sun, it is possible to see lower still in the spectrum, and A will come into view. Below A the spec-

trum is, to most people, quite invisible, and some cannot even see so far. Returning to D, and travelling from that line to more refrangible parts of the spectrum, certain definite lines will be seen about the middle of the green. These are E, and just beyond E, the *b* group—"little *b*," as it is called. In a spectroscope of small dispersion "little *b*" appears as one thin and one thick line, the thin line being nearest to E. With higher dispersion the thick line is resolved into two. A little beyond the green, just in the blue, is F. G is the centre of a group of dark lines in the violet-blue or indigo. At the extreme end of the violet are the two lines formerly spoken of as H₁ and H₂, but now called H and K. These lines require a strong light, that of sky scarcely being sufficient even when the eye is in a most favourable condition for seeing them. The writer can only see them with difficulty under any circumstances.

Below the red we have invisible rays that give a sensation of heat, and were consequently called *heat rays*; beyond the violet we have rays which the photographer's sensitive plate can receive, and which were called *actinic* or *chemical rays*. These terms never received a great amount of attention from spectroscopists, and need not be mentioned again, for they are now quite obsolete in scientific literature and conversation, the terms *infra-red* and *ultra-violet* having been substituted for them. To call the ultra-violet rays *the actinic rays* is quite absurd, when, as will be shown later on, the maximum reducing effect of the spectrum is with most compounds nearer to G.

The relative positions of the principal Fraunhoferic lines, as shown in an ordinary spectroscope, are not correct, however, the less refrangible end being compressed, compared with the more refrangible end. The effect is much the same as if we attempted to draw a scale on a piece of

paper, and made it one inch to the foot at one end, graduating it up to two or three inches to the foot at the other end. Let us represent the lines as they are seen in the diffraction spectrum (to be treated later on), at distances apart proportionate to their wave-lengths. A comparison of the solar spectrum in fig. 6, with that of fig. 7, will show how much the prismatic spectrum is distorted.



Solar spectrum according to wave-lengths.

Fig. 7.

Hitherto we have been considering the solar spectrum ; but if we examine the spectrum given by a solid body rendered luminous, such as a white-hot poker, or the particles of carbon in an ordinary gas or lamp flame, we get a spectrum perfectly continuous instead of being crossed with black lines. If we examine the spectrum of an incandescent vapour, we get a spectrum of bright lines on a dark ground. A flame containing sodium vapour, for instance, gives us a bright line in the yellow, which Fraunhofer found to be coincident with the D line of the solar spectrum (No. 2, fig. 6). If the light from a flame coloured with sodium or one of its salts be allowed to pass through sodium vapour at a lower temperature, it is found that the sodium vapour is able to absorb the very light which itself gives forth when incandescent. If the light from a gas flame be examined by the spectroscope after passing through sodium vapour, we get a continuous spectrum crossed by a dark line (No. 3, fig. 6). These facts led Professor Stokes and others to come to the conclusion

that sodium existed in or surrounding the sun, and absorbed a certain amount of the light given out by the body of the sun. In 1859 this was brought more prominently forward by Kirchoff and Bunsen, the former of whom was soon able to show that many of the other lines of the solar spectrum were due to different metals. This research was rapidly followed up, and we got to know something of the constitution of not only the sun, but many of the other heavenly bodies.

The examination of the light from different sources soon proved to be a very accurate and delicate means of analysis; sodium, for instance, can be detected in the minute particles of dust floating in the atmosphere. An expert in spectroscopy can readily analyze a substance by examining its light; but in the hands of a novice the very delicacy of the method mars its practical usefulness in the laboratory, for substances can thus be detected, the presence of which cannot be shown by other means.

CHAPTER IV.

COLOUR.

ON emerging from the prism, a ray of light is, as we have seen, spread out into a band, which produces a series of sensations on the retina of the eye, known as "colour." The question of colour is of far too much importance to be lightly passed over; it is not to be left out of the photographer's calculations, and is continually coming to the fore in all branches of his practice. That different colours—or, more correctly speaking, objects the light from which give rise to different colour sensations—produce vastly different effects on a sensitive plate, is too well known to need repetition here, and this fact is frequently bewailed. It must not be forgotten, however, that this has its advantages as well as its disadvantages; in illustration of which it is simply necessary to mention the question of dark-room illumination. It would be very awkward indeed if we had to work now as some of the early workers in photography did—in darkness. This is one of the main advantages in the inequality of the reducing action of different parts of the spectrum. One of its main disadvantages is, that the comparative luminosities are not fairly represented in the photograph; but nature

herself steps in to our aid here, in never giving us purity of colour.

The question of colour sensation has always presented difficulties—difficulties that were more readily mastered in by-gone days with very imperfect knowledge, than they can be at the present time with less imperfect knowledge. The subject is a fascinating one that has occupied the attention of many masters of science. Books have been written on the subject; and it is obvious, therefore, that only a few of the most important points can be touched upon here.

It had been known as long, probably, as the art of painting had existed, that the artist could produce from three pigments any of the other colours. The three colours which could not be imitated by mixture of other pigments were red, yellow, and blue, and these were called the primary colours. Newton's experiment seemed to add confirmation to this view, for the other tints of the spectrum were easily explained by Sir David Brewster on the supposition that they were produced by the overlapping of its three primary colours. More modern experimenters, notably Helmholtz and Maxwell, by experiments on the mixing of lights of various refrangibility (or, to use more popular terms, mixtures of coloured lights as distinguished from pigments), came to the conclusion, first mooted by Young at the beginning of the present century, that red, green, and blue or blue-violet, came nearer to being the three primary colours than red, yellow, and blue. There are three colours in the spectrum which, it is said, cannot be imitated by mixtures, that is mixtures of coloured lights; and because they cannot be imitated they are sometimes regarded as the primaries; these are the extreme red and violet, and a deep olive green.

Clerk Maxwell, however, considered the primary colours to be :—1. A red resembling the pigment vermilion, situated about one-third the distance between C and D from C ; 2. Green resembling emerald green, situated about one-fourth the distance between E and F from E ; 3. A violet-blue, situated midway between F and G, and capable of being fairly represented by artificial ultramarine.

It is not easy, however, to satisfy the spectroscopist that the eye is capable of receiving only three independent sensations of colour. From red to violet the spectrum is one beautiful gradation of colours melting imperceptibly into one another; the greater the dispersion the more noticeable does this become. True, the eye is not delicate enough to distinguish between the tints of two lines lying very close together, and yet it has been estimated that about a thousand different tints can be counted. Each of these tints would be regarded as a primary colour, were the wave length producing it the only factor brought in to decide what is a primary colour, and what is not. The difficulty of arriving at a true explanation of the sensation of colour is due to our lack of knowledge of what takes place after the waves of light reach the retina. It is known that there are certain structures there called rods and cones, which have something to do with carrying the sensation of sight to the brain, but that is all. The three-colour sensation theory has to rest on an assumption that each terminal of the optic nerve ends in three organs, which are capable of responding to certain portions of the spectrum, and each wave of light (unless it is capable of causing one of the three primary colour sensations) produces two, and sometimes three, distinct sensations. Anatomy has no knowledge at present of any such structure, and the theory at present rests on evidence derived

from experiments with coloured lights, and on deductions from the study of colour blindness. The subject is in a somewhat unsatisfactory condition, and, as already mentioned, authorities hold different opinions as to what reds, greens, and violets are primary, after all.

But be the explanation of colour sensation what it may, the artist will take the old view of the question Colour and pigment are to him such interchangeable terms, that to him there always will be three primary colours, but *his* primary colours will be red, yellow, and blue, as of old. The three-primary-colour theory has been to him, and is likely always to be, a valuable working hypothesis, and, providing that *pigments* are understood, there can be little objection to its retention.

The writer must ask the reader's pardon for this little digression. The interest attaching to this still debateable subject is common to all, especially to photographers, who are not indifferent to the subject of colour, although their results are produced in black-and-white, and this interest must be my apology. It is only a digression in this sense : that the explanations of colour-phenomena that the photographer meets with are comparatively simple, and do not require the aid of any such theory. The retina of the camera, if such an expression may be used, is well understood. The sensitive plate is a ground capable of being influenced by certain portions of the spectrum. It may be said to possess, in a transcendent degree, that colour sense which to us is weakest, namely, the blue. As will be shown in the next chapter, we may say in a general sense, that it is the *most* refrangible portion of the visible spectrum which produces the *most* effect on a plate. We have, therefore to consider the nature of the light received from terrestrial objects, paying most attention to the blue. A

brief consideration of what takes place in reference to coloured glasses and pigments is all that is required to properly understand the matter.

If a piece of yellow glass be placed before the slit of the spectroscope it will be seen to cut off a lot of the violet and some of the blue, letting most of the green, yellow, orange, and red pass through. The yellow colour is given to the glass by the combination of tints that pass through it. If a piece of cobalt blue glass be examined, it will be seen that it derives its colour from the violet and blue rays chiefly, as well as to parts of the green, yellow, and red. Its absorption takes places by two bands in the red, and a smaller general absorption along the red, yellow, and green. If these two glasses be placed in contact, it will be found that they appear green, the spectroscope showing that it is the green and green-yellow rays which find their way through. But if these two glasses be placed in separate optical lanterns, and the lights be projected on the same screen, it will be found that white light is produced tinged with yellow or blue according to the colour that is strongest. In the first case we have the difference, in the second case the sum, of the rays which they transmit.

A mixture of pigments resembles more the first than the second of these two cases ; the light sent to the eye is chiefly that which neither of them absorbs. Hence it has been said that "every mixture on the artist's palette is a step towards blackness."* What we meet with in nature is analogous to the effect produced on white light by a pigment, and just as we seldom find pigments that reflect light from a limited portion of the spectrum only, so do we seldom or never meet with pure colours in nature.

* Rood's "Modern Chromatics."

They may be pure in the artist's sense of the word—that is, they may be clear and bright—but never pure in the sense that the spectroscopist uses the word.

In addition to this lack of purity in colours, all objects reflect more or less white light from their surfaces as well. A striking instance of this, for example, may be observed by looking at grass or foliage in bright sunshine through cobalt blue glass (as pointed out by Mr. Woodbury*), or through permanganate of potash ; it is surprising how red they appear, that colour appearing to predominate over the rest. But for this reflected white light it would be almost impossible to get detail of objects otherwise lacking in rays of high refrangibility without very considerable over-exposure in others.

* Tyndall on Light.

CHAPTER V.

THE REDUCING ACTION OF THE SPECTRUM ON THE HALOID SALTS OF SILVER, APPLIED TO THE MAKING AND WORK- ING OF SENSITIVE FILMS.

HAVING acquainted ourselves to some extent with the different parts of the spectrum, and glanced briefly at the phenomenon of colour, we are now in a position to examine in detail the action of the spectrum on the principal compounds which the photographer uses. It has already been stated that it is the *most* refrangible portion of the visible spectrum which has the *most* reducing action on sensitive plates ; this is only, of course, to be taken in a general sense, for it is found that all compounds, even all silver compounds, are differently sensitive, but the alliterative use of the word "*most*" may be a useful aid to the memory of the beginner if he is not above accepting artificial aids to his mental powers. Referring once more to the three primary colour sensation theory, and speaking, again, in a general sense, we may regard the sensitive plate as possessing in a transcendent degree only the blue sensation. A once very popular impression, and one that even now exists, to some extent, was that the greatest

effect was produced by the rays beyond the violet. How far this is the case we shall soon see; but in the mean time, it may be mentioned, that it certainly appears to be the case so far as the chloride of silver is concerned, the substance whose sensitiveness to light was first noted.

One of the first things that the scientific investigator—aye, and the scientific student, too—has to learn, is to follow the rule that nothing is to be taken for granted. Adopting this principle in the present discussion, and verifying each statement by personal experiment, will not be found a difficult task, when the necessary amount of care and patience is exercised. The mode of procedure, though simple, is worth a brief statement.

The source of light is the first consideration, for it is obvious that the result will vary with the method of illumination. As the light we meet with in nature is emitted by the sun, we need go no further for a source of illumination that shall enable us to make an examination that may go fairly in hand with our ordinary photographic experience. Directing a beam of sunlight on to the slit of the spectroscope by means of a mirror, and condensing the rays on to the slit by means of a lens, in order to shorten exposures, a plate is placed in the dark slide of the camera, and exposed and developed. Assuming that the plate has had sufficient exposure to receive all that it can receive, what do we notice? Leaving out of consideration the Fraunhoferic lines—or rather, using them as an index only—it will be noticed that the image possesses different shades, a gradation of density falling away on both sides of some particular region. This gradation of density gives us a rough idea of the relative sensitiveness of the medium to different parts of the spectrum. To get a more accurate notion, a few more exposures are necessary. A very rapid

exposure will show what part of the spectrum produces the greatest effect, for that part will be the first to be impressed. A little longer exposure will show what part is next easily impressed, and so on. By this means we are able to get a very correct notion of the action of different parts of the spectrum on the particular kind of plate that is being used, and by combining these photographs, representing the action of each part of the spectrum by a line proportionate to its intensity, and drawing a curve upon them, we get a very graphic representation.

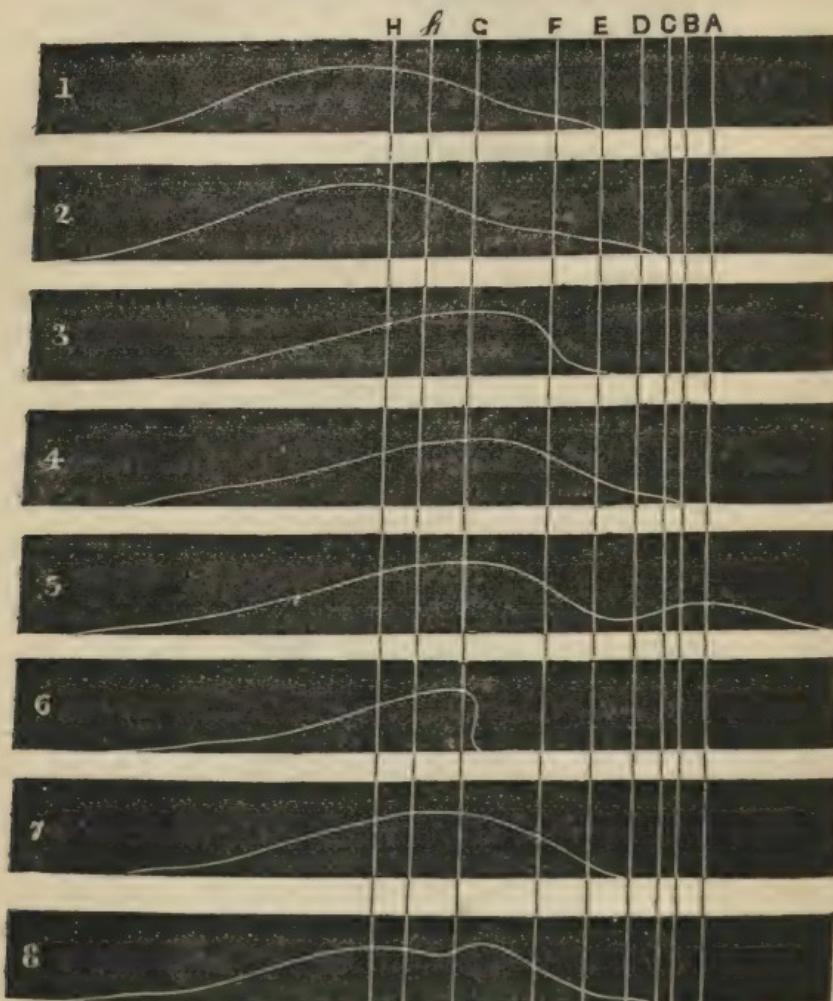
The investigation of the action of the spectrum on substances sensitive to light has been followed up from the earliest days of photography. It may be said to have begun before the days of photography or spectroscopy, for when, in 1777, Scheele stated that the violet rays had the greatest blackening action on silver chloride, he had only the impure spectrum as given by Newton's experiment to work with, and, as the reader knows, it was not for many years after that date that the first delineation of an object was produced by the action of light. To give an account of all that has been done since then has formed the subject of a book only recently,* and those who appreciate that book most, must regret its brevity. In these articles only a few of the best known compounds and combinations can be spoken of, and only the most recent researches. Not long since, a careful examination of the haloid salts of silver was made by Captain Abney,† and the effect of the spectrum was graphically, as well as verbally, delineated by him. The accompanying diagram gives the result of an examination of those compounds in which the general worker will be most interested. Captain

* "The Chemical Effect of the Spectrum."

† Proceedings Royal Society.

Abney's results do not differ very materially from the work of others in this direction, and the reader can readily test them for himself.

Fig. 8.



- 1. Yellow chloride of silver.
- 2. Grey chloride.
- 3. Orange bromide.
- 4. Grey bromide.
- 5. Green bromide.
- 6. Pure iodide.
- 7. Iodide, bromide with nitrate of silver.
- 8. Iodide and bromide in gelatine.

Chloride of silver, in its yellow state, it will be noticed, has its maximum near H, which is about the extreme limit

of the visible spectrum. It is sensitive far up into the ultra-violet, and in the lower part of the spectrum it comes down to about F, its sensitiveness thus stopping short at about the commencement of the green. The grey form of chloride—that is to say, a chloride emulsion which has been boiled—is most sensitive at the same place as the unboiled, but it is sensitive to a greater range of the spectrum, the boiling of the emulsion having made it sensitive as far as D. Bromide of silver is most sensitive midway between G and F, well into the dark blue. The orange or unboiled emulsion, whilst its maximum is in the same place as that of the grey form produced by boiling or by the ammonia process, only goes down as far as E, about the middle of the green, whereas the grey extends as far as B in the red. Pure iodide of silver is most sensitive at about G, and the curve ends very sharply. The addition of bromide makes it extend much lower, and when further reinforced by the presence of free nitrate of silver, as in the wet plate process, we get a considerable range of sensitiveness. With a mixture of bromide and iodide in gelatine we get two maxima, the most sensitive point, as might be anticipated, coinciding with that of pure bromide. At the point where the maximum of the iodide should be, we get a depression in the curve, the mixture of the two salts being less sensitive there. In this curve, however, we have the result produced when a considerable quantity of iodide is present; in the emulsions containing iodide, which the photographer usually works with, the loss of sensitiveness at G is comparatively small and scarcely appreciable, so far as his work is concerned.

Now several questions arise in looking at the different effects produced on different salts. First of all, there is the consideration of what kind of plate will be the best for

photographing a particular part of the spectrum, supposing we are making spectroscopic researches in which we are calling in photography to help us. This, so far as the substances already considered are concerned, is a simple matter, and need not be dwelt upon. It is obvious that chloride, if we succeed in getting it in its most sensitive state, whilst we can also develop it free from fog, is the best for work in the violet and ultra-violet portion of the spectrum. For rays below G, and for all-round work, the bromide is the best. Again, if we are using the wet collodion process, it is plain that a mixture of bromide and iodide will give us far better results than iodide alone. Secondly, we have to consider what salt is best for ordinary photographic work, and in what ways may the different salts be utilized in order to work to the greatest advantage. In connection with this it is necessary to consider the question of atmospheric absorption so far as it affects the light that impresses the image. Lastly, there is the action of heat upon a sensitive salt in the preparation of plates, and the application of spectroscopic research in settling doubtful points. These last two questions, however, must be left over for the next chapter.

CHAPTER VI.

THE REDUCING ACTION OF THE SPECTRUM ON THE HALOID SALTS OF SILVER, ETC., APPLIED TO THE MAKING AND WORKING OF SENSITIVE FILMS—*continued.*

IN considering the relative values of the different haloid salts of silver for ordinary photographic purposes, the question arises—"What rays can we most conveniently work with?" There can be no question as to what rays would be most suitable, if we could get a good ground for them to act upon, for since the yellow rays have the greatest effect upon the eye, the photographer would obtain results more nearly approaching to what we see in nature by using a medium more sensitive to that part of the spectrum than to any other. But, as he knows full well, these rays have an almost inappreciable effect upon the substances he finds most readily workable. Taking the three compounds, chloride, bromide, and iodide of silver, and arguing from theory alone, the choice lies between the two first. Could iodide of silver be obtained in an emulsion in a readily developable condition, it possesses a great drawback in its comparatively small range of sensitivity to the spectrum. The fact that its sensitiveness

ends abruptly in the dark blue near G would place it out of the competition unless it could be rendered very sensitive indeed, and though it extends lower in the spectrum when sensitized by nitrate of silver, it will be readily seen what an advantage was gained in the wet process by the addition of bromide to the collodion. Chloride of silver is sensitive almost as low down as bromide, but its maximum of sensitiveness is in the ultra violet. Now since the ultra violet rays are largely absorbed both by the atmosphere and by glass, there can be no doubt, theoretically, that the practical man is doing right by making bromide of silver the corner stone of his industry. In bromide of silver he has a substance possessing a great range of sensitiveness, and he is using rays the quantity of which can be to some extent estimated by the eye. Chloride and iodide of silver can both be added to emulsions with advantage, but they must occupy only a secondary place. Chloride of silver, which is not so often present in a film as it might usefully be, will be found to confer a great increase in sensitiveness in summer weather, and for work in tropical climates is an invaluable addition to plates used for so-called instantaneous exposures.

The writer has found that emulsions containing about ten per cent. of chloride and three to five per cent. of iodide, whilst possessing at home all the good qualities of a slow working plate, latitude in exposure, density, &c., have been found to be more rapid in the tropics than many plates which he has regarded as highly sensitive at home. It is a moot question whether chloride of silver should be added to a bromide of silver emulsion after boiling, or should be emulsified at the same time and boiled with it. Adding the chloride emulsion after boiling would appear to be the best method of procedure, for this reason—that

chloride of silver cannot be boiled as long as the bromide without running the danger of fogging it. It would seem advisable, therefore, to make an ordinary bromide or bromide and iodide emulsion first, raise it to the highest possible degree of sensitiveness, and then add the desired quantity of a chloride emulsion that has received as much boiling as it will stand, and will give a clean transparency with ferrous-citro-oxalate developer. There is still the question whether chloride and bromide of silver when emulsified together form a double molecule? But if so, this cannot greatly affect the result, for the double molecule is, in the other case, formed during exposure. One disadvantage in the addition of chloride may be mentioned here, though it does not come directly within the scope of these articles—viz., that with the alkaline developer one runs a greater risk of green fog, and the ferrous-oxalate has to be used for safety's sake.

The use of iodide in an emulsion in anything like the small proportion usually adopted is rather a question for the emulsion maker than the spectroscopist. When present in a small proportion, it has many beneficial effects—notably, cleanness in working, latitude in exposure, and prevention of halation. Emulsions should not contain more iodide than is found sufficient to produce these effects; five per cent. will generally be found sufficient, and at most it is hardly advisable to go beyond eight per cent. Even with this small proportion, there is, according to Captain Abney, a slight loss of sensitiveness near G, although the emulsion itself may be quite as sensitive in the camera as one of pure bromide. Where a large proportion of iodide is used, the image obtained is usually thin. Another advantage in favour of a small percentage of iodide is, that it lowers the sensi-

tiveness of the emulsion towards the red, and enables one to work with a brighter light in the developing room; and as the sensitiveness of a gelatino-bromide plate to the less refrangible rays is very small as compared with its sensitiveness to the blue rays, an advantage is met with in actual practice by doing away with the sensitiveness to the yellow and red altogether, if possible. The general opinion is, that iodide is best emulsified after the bromide and before boiling, in order to get as fine a state of division as possible; and though an emulsion containing iodide takes longer in the boiling process than one of pure bromide, quite as high a sensitiveness may be obtained, with less danger of over-boiling.

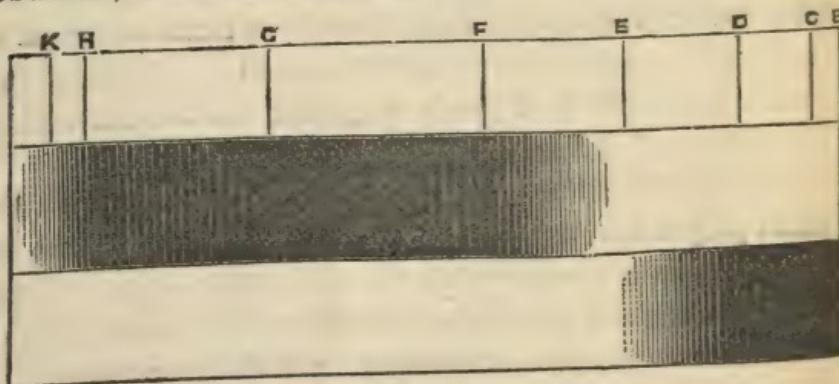


Fig. 9.

1. Fraunhoferic lines.
2. Spectrum on bichromate (carbon tissue).
3. Rays bichromate allows to pass through.

In considering the behaviour of different substances when exposed to the spectrum, there is one point which must not be overlooked; this is, the relation existing between the colour of the substance and the rays which act upon it, or, in other words, the relation between absorption and work. The best illustration of this that can be given is the case of some transparent medium such as an alkaline bichromate. In the accompanying diagram, taken from a transparency

kindly lent me by Captain Abney, and shown by him at several of his lectures, it will be seen that the rays which the bichromate absorbs are those rays which reduce it in the carbon printing process.

With the haloid salts of silver, this relation of absorption to work is not quite so noticeable, as, instead of a transparent substance, we have a number of semi-opaque particles, and a certain amount of white light passes through in addition to that rejected by the particles. Nevertheless, the absorption of light in the parts of the spectrum which act on the sensitive film is sufficiently marked to render prominent the distinctions between chloride, bromide, and iodide of silver.

It has been shown (fig. 8, Nos. 1 and 2) that in the case of chloride we can have it in two states, yellow and bluish-grey, the former being unboiled, and the latter the boiled. Iodide can also be obtained in two corresponding states, but the effect of heat can best be studied with bromide of silver, for the simple reason that we know more about it. The increase in sensitiveness is usually regarded as a consequence of the increase in the size of the particles brought about by boiling; the boiling may be carried so far, however, as to produce a very coarse—almost insensitive—form. There are several different states in which bromide of silver can be obtained, but the differences are in some cases not so marked spectroscopically as they are to the eye.

We have, in the first place, the orange form of bromide; on boiling, or by the ammonia process, this is converted into a bluish grey, perfectly distinct to the eye. When acted upon by the spectrum, and developed, however, it is found that there is very little difference in them after all, the boiling having been mainly instrumental in rendering

the compound more sensitive ; the maximum remains the same, but the blue-grey form extends further towards the red. It does not appear likely, therefore, that we shall be able successfully to borrow an idea from the Bessimer steel process, and see, by the spectroscope, when our emulsion is sufficiently cooked ; for if the light passing through a boiled and an unboiled emulsion be examined by the spectroscope, it will be found that the cooked bromide derives its bluish tint from a small amount of orange-red and red light which it absorbs over and above its absorption when unboiled. The eye-test without the spectroscope will be found the best guide.

It is still a moot question whether silver bromide in gelatine differs from the same salt suspended in collodion. Spectroscopically, the difference is not very noticeable, but with the previously-mentioned example showing what a contrast to the eye a slight difference in absorption may produce, this cannot be allowed much weight. On various grounds, given at length in the PHOTOGRAPHIC NEWS, Dr. Vogel draws a marked distinction between the two, calling the silver bromide in gelatine the blue-sensitive form as distinct from indigo-sensitive, the term he applies to silver bromide in collodion. According to Dr. Vogel, the sensitiveness of modern dry plates is due to the blue-sensitive form becoming considerably more sensitive on boiling than the indigo-sensitive form. It must be noted here, that Dr. Vogel is careful to use the terms *blue-sensitive* and *indigo-sensitive*, not *blue* and *indigo*, the term *blue-sensitive* applying as much to the boiled as the unboiled bromide of silver in gelatine ; the term *indigo-sensitive* has a similar application, referring to the point in the spectrum at about which the maximum comes.

Bromide of silver can be obtained in a form markedly

different from any of the preceding by boiling a collodion emulsion with a large excess of nitric acid. In this state it is distinctly green, but may be brought back to the orange state by rubbing. This form of silver bromide, which Captain Abney uses for photographing the ultra-red rays, has two maxima (fig. 8, No. 5), the ordinary maximum near G, and another an octave below it. With this form, the ordinary photographer is hardly likely to have anything to do, but it will be as well to note that it differs entirely from gelatino-bromide emulsions which have been prepared for photographing the red end. With these latter we do not get the formation of a second maximum, but merely a continuation of sensitiveness towards the less refrangible portion of the spectrum, a fact which must be borne in mind when considering what light it is advisable to use to illuminate the dark-room.

CHAPTER VII.

SENSITIZERS, AND THE ACTION OF THE SPECTRUM ON SALTS USED IN THE PRINTING PROCESS.

So far we have simply been considering the effect of the spectrum on the haloid salts of silver alone, and in the obtaining of a negative picture ; but before leaving this subject, it will be well to note what effect is produced by the addition of other substances, notably dyes, a subject that is at present engaging considerable attention. The effect of sensitizers in the film—that is to say, sensitizers the only function of which is to absorb the halogen freed by the action of light—is, in most cases, simply to decrease the time of exposure by increasing the sensitiveness of the compound in the film. When used with a film containing a mixture of two or more haloid salts, they perform another function. The decrease in sensitiveness at a part of the spectrum, caused by the action of one halogen set free on the compound of another halogen with silver, is removed. This will be seen by a reference once more to fig. 8, Nos. 7 and 8, showing the effect produced when nitrate of silver is present as a sensitizer to a mixture of iodide and

bromide of silver. In such a case as this, the sensitizer takes up the halogen as soon as the light sets it free. It may be remarked that gelatine is too feeble a sensitizer to produce such an effect in any marked degree, and it may therefore be noted incidentally here, that whatever be the cause or causes of the sensitiveness of modern dry plates, the function of gelatine in inducing sensitiveness would appear to be physical rather than chemical.

The addition of certain dyes to films containing sensitive compounds has the effect of increasing the sensitiveness of those compounds to certain rays; in most, if not all, cases, to those rays which the dye absorbs. It is a debated question as to how this takes place, whether the dye, by absorbing the light, causes it simply to act more energetically on the silver salt, or whether the dye itself undergoes a change. It has been pretty well ascertained that those dyes only which are not permanent, can act as "optical sensitizers"; "colour sensitizers" or "local sensitizers" would, perhaps, be a better term. The action of these colour sensitizers is greatest when a chemical sensitizer is also present; but the latter is not indispensable, as many dyes possess this property as well. To mention briefly a few dyes that give a local increase of sensitiveness, we have:—Coralline, increasing the sensitiveness to light blue near F; aurine, increasing the sensitiveness to the green; aldehyde green for both yellow and blue; methyl violet for the yellow near D; eosin, increasing the sensitiveness in the green between E and F; cyanine blue for the yellow and orange-yellow, about D and C. Of these the last two are the most important; but until lately it has been found that the sensitiveness in the parts of the spectrum where the dye absorbs is still not greater than at the natural maximum of the haloid salt.

In the preceding articles of this series, it was stated that, "since the yellow rays have the greatest effect upon the eye, the photographer would obtain results more nearly approaching to what he sees in nature by using a medium more sensitive to that part of the spectrum than to any other." It will be seen, therefore, that the influence of dyes in the film is of considerable importance. Its importance is pretty generally recognized so far as the photographing of paintings is concerned, and the use of dyes has in this direction been attended with beneficial results, in spite of the fact that the local sensitization has hitherto been far below the amount desirable. Dr. Vogel's recent claim to have produced plates twenty-five times as sensitive to the yellow of the spectrum as to the blue, if substantiated, should be productive of most important results, and the photographic world, if fully alive to the benefits attainable, will bear with some impatience the short time that must elapse before they can obtain the material with which they can try Dr. Vogel's process.

It remains now to consider the effect of the spectrum on sensitive compounds in relation to printing processes. In this we have to consider the action of light on silver chloride in the presence of nitrate of silver and organic matter; the action of light on iron salts, on which the blue process and the platinotype are based; and the action of light on bichromate of potash, on which the carbon process is based. These are the most important compounds with which we are accustomed to deal.

In the reducing action of light on the haloid salts of silver there is little difference between the result produced by printing and that by development, so far as the extent of action in the spectrum is concerned, the maximum remaining in both cases the same. Bromide and iodide of

silver not being adapted for printing purposes, on account of the comparative feebleness of the image compared with that of the chloride, may be dismissed. The effect of the spectrum on chloride of silver on paper in the presence of nitrate of silver is shown in the accompanying diagram.

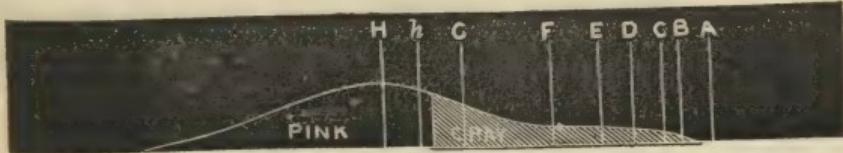


Fig. 10.

It will be seen that the more refrangible part of the spectrum, beginning from a point almost midway between H and G, a little less refrangible than *h*, darkens the paper to a somewhat pinkish or ruddy hue. Below *h* the tint produced is greyish. In the ordinary silver printing process we have other compounds of silver present, notably the albuminate. It will be found, however, that the most refrangible rays darken the paper a redder tone than do the less refrangible rays, whether commercial ready-sensitized paper be used, or the paper be sensitized when required. This is the general rule, though different papers will give particular differences under the action of light. The difference in colour produced by different rays will explain several phenomena with which everyone is more or less familiar. Let us, in the first place, consider the subject of printing by the electric light, as this will make what follows plainer.

Those who have tried printing by the electric light must have noticed what ruddy pictures are obtained. This is undoubtedly due to the quantity of rays of high refrangibility emitted by the arc light. Further, the same amount of contrast is not obtained that may be got when printing by diffused daylight, or even by the direct rays of

the sun, and defects in the negative which hardly appear when printing by the sun, come out forcibly under the light from the electric arc. It would appear that the ruddy compound produced by rays of high refrangibility is more opaque to ultra-violet rays than the grey form, so that whilst the rays are slowly penetrating the reduced surface, they have time to penetrate through the dark parts of the negative. There is nothing to be surprised at in this when it is remembered that metallic silver in a thin film (as in the mirrors used by astronomers) is transparent to some of the ultra-violet rays.

This will explain the advantage found in printing by diffused daylight in preference to the direct solar rays, especially with weak negatives ; the light reflected from the clouds having been deprived of some of its ultra-violet rays. Again, negatives developed by ferrous oxalate, print redder than negatives developed with alkaline pyro, the yellow stain of the latter cutting off some of the more refrangible rays.

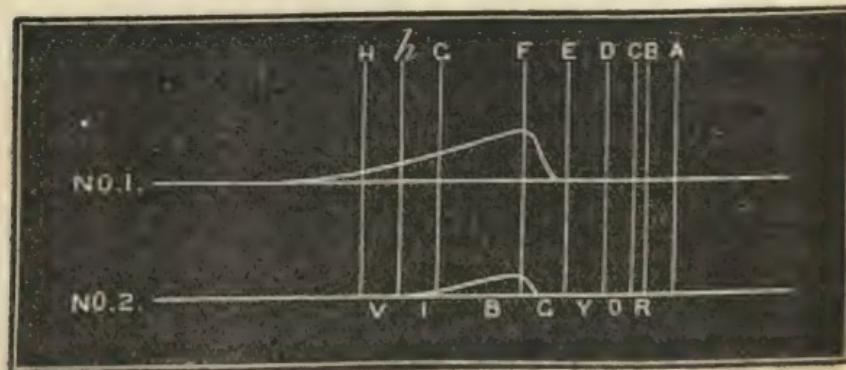


Fig. 11.

The action of the spectrum on iron salts can be dismissed in a few words. The action is very similar to that of the spectrum on bromide of silver.

The carbon process possesses a very considerable advantage over silver printing or processes depending on the reduction of iron salts. The above diagram* will show that the maximum effect of the spectrum on bichromate of potash is near F, in the light blue. The carbon process can therefore be worked in a much weaker light than either silver printing or platinotype.

* From "Instruction in Photography," by Captain Abney.

CHAPTER VIII.

ILLUMINATION OF THE DARK ROOM.

WHEN we read that the feeble actinism of the red rays was noticed in the beginning of the present century, that the Daguerreotype was not introduced till 1839, and the Calotype of Fox Talbot till 1841, it is somewhat singular to find that developing by a light sifted through coloured glass does not seem to have been introduced till Claudet made it the subject of a patent in 1844. Whether early photographers performed their operations in darkness, or in a very feeble light, we are left to guess ; but this much is certain, that the system that has been in vogue since the time of Claudet was delayed for some years through a disregard of facts which physicists had drawn attention to over forty years before. At that time the spectroscope in its present state was unknown ; but that did not deter early experimenters in compounds sensitive to light from testing the power of different rays with the rougher apparatus at their command—the simple prism and hole in the shutter of Newton. Wollaston also tried the effect of coloured glasses, and Becquerel recommended that such coloured glasses should first be examined by the

spectroscope, before the date of Claudet's patent. Since Becquerel's time the spectroscope has played an important part in the investigation of this subject, and it can readily be shown that the spectroscopic test, if properly carried out, is one that can safely be relied on, and, in its very simplicity, is superior to the somewhat haphazard methods more frequently adopted.

There are three things to be taken into consideration in the investigation of this subject :—First, the action of the spectrum on the sensitive compound used; second, the absorption of the glass and the illuminating effect of the light which passes through the absorbing medium; third, the comparative comfort—or, rather, the comparative lack of discomfort—of the light passing through the absorptive medium, this last-named consideration being mainly one of individual choice.

In considering the first of these, we are practically limited to one thing—the action of the spectrum on bromide of silver in its normal physical state, omitting, therefore, the state of bromide of silver when prepared in collodion by Captain Abney's process for photographing the red end. As iodide of silver, and a mixture of bromide and iodide of silver, are barely as sensitive to the visible rays of low refrangibility as pure bromide is, it follows that a light suitable for working bromide of silver in, is also suitable for the manipulation of plates containing iodide.

Bromide of silver, as has already been shown, is most sensitive in the blue rays, and it is absolutely necessary, therefore, that all rays in the blue and above the blue should be discarded for dark-room illuminating purposes. Below F, which is near the lower end of the light blue, the spectrum shows a marked decrease in its action on silver bromide. From F down to E the decrease is still more

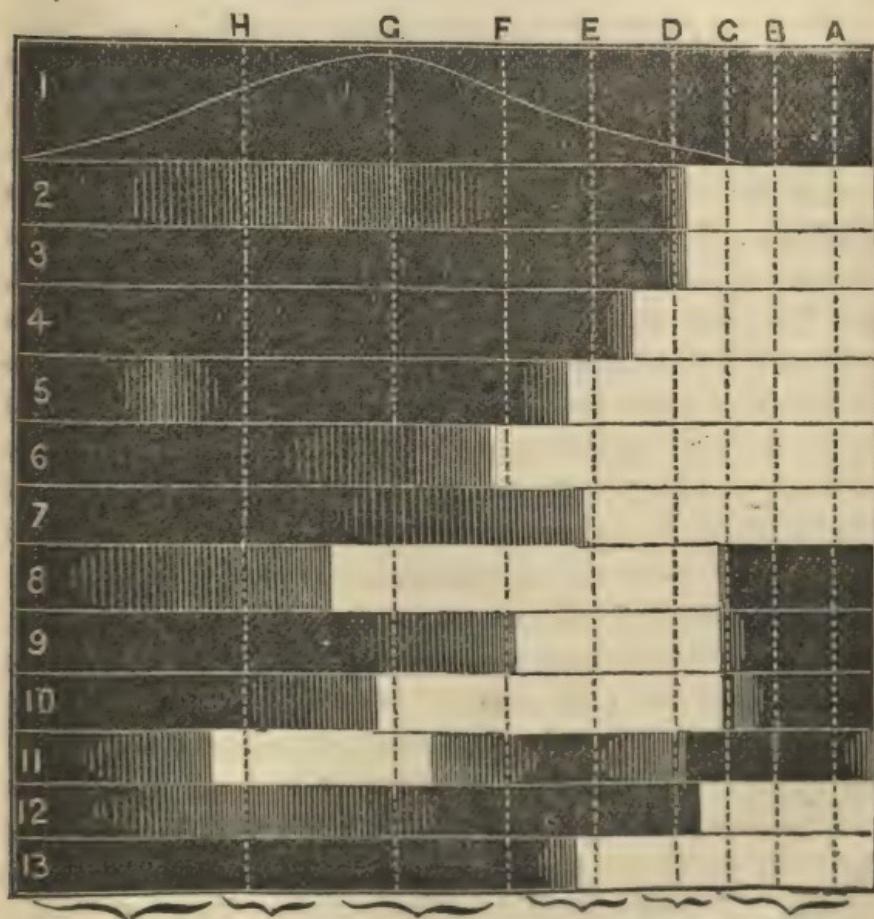
marked ; and from E down to the red the action of the spectrum decreases at a regular rate. How low down in the spectrum any action is produced, depends mainly on the rapidity of the emulsion and the length of exposure.

This brings us to the second consideration. It is pretty obvious that the medium we use should not let through any rays above E ; we are limited, that is to say, to that part of the spectrum from the yellow green downwards. Moreover, but for the high illuminating power of the yellow, and the fair illuminating power of the yellow-green, giving a comparatively large amount of illumination in proportion to its reducing power, our choice would lie within still narrower limits.

What medium, then, best fulfils the required conditions ? In considering this, it will be well to look at the method of testing adopted by the spectroscopist, as a consideration of his *modus operandi* should silence some of the loose talk one is still apt to hear in photographic circles as to the supposed discrepancies between spectroscopic evidence and ordinary practice.

In the first place, one has recourse to an eye observation. Allowing a beam of light to pass through the instrument, the medium to be tested is placed in front of the slit, and its absorption noted. This is but the first rough test, however. The medium may let through some ultra-violet rays, which, being invisible, would escape detection by the eye, as in one important medium that may be instanced. It is necessary, therefore, that a photograph should be taken in the spectroscope ; such a photograph will not only show what portions of the spectrum the particular medium lets through, but will also give the relative reducing effect of the light which passes, showing, therefore, in addition, what rays may still be advan-

tageously dispensed with. It is found that there is no part of the spectrum which produces absolutely no effect if the exposure be sufficiently prolonged, and the problem



Ultra-Violet. Violet. Blue. Green. Yellow. Red.

1. Curve showing action of spectrum on bromide of silver.
2. Absorption of ruby glass.
3. Three thicknesses of ruby glass.
4. Stained red glass.
5. Orange glass, a lighter form of stained red.
6. Yellow glass.
7. Amber glass.
8. Signal green.
9. Yellow green.
10. Cathedral green.
11. Cobalt glass.
12. Magenta dye.
13. Aurine.

to be solved, therefore, may be briefly stated in the five words, "maximum light with maximum safety."

The foregoing diagram indicates roughly the absorption spectra of various transparent media.

It will be noticed that a single thickness of ruby glass cuts off the greater part of the spectrum above and including the yellow, but it also allows some blue and violet rays to pass through; in quantity this blue and violet is small, but it has a considerable effect upon the plate. There is, of course, some slight amount of general absorption in the red which cannot readily be represented in a diagram. If two thicknesses of ruby glass be taken, the amount of blue and violet light which passes is very small, and with three thicknesses it practically disappears. With each additional thickness of glass the general absorption in the red is also increased, so that three thicknesses of ruby appears considerably darker than one, but the additional safety is greater in proportion to the loss of light. Next, we have stained red, a glass recommended by Captain Abney, the particular kind he uses being stained a deep red on one side and yellow on the other. Lighter tints in stained red are also to be met with, one of the best orange glasses being of this character. When examined by the eye through a spectroscope, it appears almost as safe as the darker stained red, but a photograph shows that it lets through a small amount of ultra-violet rays at or about the same place as the rays which find their way through a thin film of silver. Yellow glass lets through blue rays in addition to green, yellow, and red; the amount of blue and green which passes varying considerably with the depth of the yellow stain. A glass that was used very frequently in wet plate days is amber, sometimes erroneously called orange. Even when deeply coloured, amber glass allows a certain amount of blue to pass, and its general absorption is very

considerable, so that when sufficiently thick to ensure moderate safety, its illuminating effect is weak compared with other media. The absorption of the two most important greens, signal green—which is almost a blue—and yellow green, are shown in 8 and 9. In No. 10 we have the absorption of a slightly tinted glass commonly used for the windows of ecclesiastical edifices, and generally known in the trade as "cathedral green." This glass varies considerably in tint, and the makers will only guarantee a particular shade when very large quantities are required; the diagram, therefore, cannot be taken as representing the absorption of all glass sold under the name. By itself it is practically useless for photographic purposes, and was introduced by Mr. Debenham for use with other media, to cut off the lower part of the red in the spectrum. In No. 11 we have the absorption of cobalt glass, the red between A and B, and most of the blue and violet, passing through with but little absorption. In 12 and 13 the absorption of magenta and aurine dyes are given. The first named allows all the red and orange and some of the blue and violet to pass, the latter giving a passage only to rays less refrangible than the blue. The two combined furnish a good medium when dissolved in varnish.

Stained red, letting through only the red, orange, yellow, and a little yellow green, approaches, if it does not actually reach, the ideal which spectroscopic experiment and ordinary practice proclaim as the most suitable medium. Careful experiments carried out in accordance with usual methods of manipulation, details of which would be out of place in these articles, show that it gives the maximum amount of illumination with maximum amount of safety. Modifications may, however, be conveniently introduced to suit the eyesight of the manipulator. Those to whose eyes

yellow light is irritating may with advantage introduce a thickness of ruby, and thus work only with red and orange light. Those who dislike red light may cut off a great deal of it with a sheet of cathedral green, but at the same time they also sacrifice a small amount of the yellow as well, and weaken the illuminating power of the light in much greater proportion than they increase its safety. The illuminating effect of the light passing through good stained red bears a much greater ratio to its effect upon the plate than does a combination of stained red with either ruby or cathedral green. Those who can see well with rays of low refrangibility will find a good combination in stained red and cobalt glass, and will be using that portion of the visible spectrum which possesses the least reducing power.

So far, we have simply been considering the absorption of transparent media, but it is usually found convenient to diffuse the light by some translucent substance, such as thin tissue paper or ground glass. This will be found preferable to using the fabrics and papers which have been recommended from time to time, inasmuch as they derive a considerable amount of what safety they possess from their general absorption along the whole spectrum. This is particularly the case with canary medium. Of all the media of this character which have been proposed, the best by far is the common orange paper, frequently used for packing plates. The illuminating power of the light which passes through it is very considerable, compared with its action on a gelatino-bromide plate.

CHAPTER IX.

FLUORESCENCE AND PHOSPHORESCENCE.

THESE two analogous, if not identical, phenomena demand our attention, inasmuch as one of them, at least, is familiar to the photographer, by reason of the important part it plays in the measurement of the brilliancy of light, and more particularly in the determination of the rapidity of gelatine plates.

Fluorescence was first investigated by Stokes, about thirty years ago, he having proposed the name on account of this peculiar property being possessed by fluor spar (fluoride of calcium), in connection with which it was first noticed in a high degree. Fluoride of calcium is met with in nature of various colours, green being one of the most common; but, if placed in a light rich in ultra-violet rays, it glows in a manner more readily noticed than described. A solution of quinine, which is itself colourless, fluoresces with a bright blue colour; eosine dye, in itself of a crimson red, fluoresces with a bright green colour. Canary glass, which is coloured with uranium, derives its value for ornamental purposes from its fluorescent nature.

If we place a piece of white paper or cardboard coated

with a solution of quinine in the spectrum, it will be noticed that the rays beyond the violet become visible, appearing in colour a bright lavender blue. The same thing may be equally well shown by using common lubricating oil, as recently pointed out by Captain Abney. Eye-pieces containing a fluorescent substance have been made for the spectroscope to facilitate observation in the ultra-violet portion of the spectrum. They are not extensively used, however, inasmuch as photography furnishes the readiest means of investigating the more refrangible portion of the spectrum.

Phosphorescence is most familiar to us in connection with luminous paint and the luminous tablets used with our sensitometers. Here we have an absorption of light by exposure to some brilliant source of illumination, and a subsequent and comparatively slow emission of it. Becquerel, who has made this subject a study, found that nearly all bodies are phosphorescent; but, in most cases, the phosphorescence is so small, and the light is emitted so soon after exposure, that it requires a special piece of apparatus (which he devised) to show it. As in the case of fluorescence, phosphorescence is caused by absorption of the *ultra-violet rays*, and the emission of rays of lower refrangibility.

That substances should absorb light, and be capable of storing it up for some little time, so that it may be afterwards utilized, is a phenomenon which is apt to cause some surprise, and at first sight appears difficult of explanation. Phosphorescence, however, is strictly analogous to another phenomenon that everyone meets with in his every-day experience, and which, moreover, he usually thoroughly understands—namely, the conversion of light into heat. When light falls upon a body capable of

absorbing it, the temperature of that body is raised, and it radiates heat, or sends out *dark rays* to other bodies surrounding it. We have an indirect conversion of rays of high refrangibility into rays of lower refrangibility. So with phosphorescence: rays of very high refrangibility and short wave-lengths, the invisible rays beyond the violet, are absorbed, and rays of lower refrangibility, but still of sufficiently short wave-lengths to excite the retina, are emitted. Considering the resemblance of phosphorescence to the conversion of light into heat, it is little wonder, therefore, that the phenomenon is almost universal.

Among the substances that most readily exhibit phosphorescence are the sulphides of the alkaline earths, the sulphide of calcium being that which is used for making luminous tablets for photographers. If a tablet has been kept for a long time in the dark, so that it has lost all its luminosity, and be then exposed to the spectrum, it will be found that luminosity is excited strongly where the ultra-violet rays have fallen, the luminosity decreases where the violet rays have fallen, and stops short in the dark blue or indigo near G. If the tablet be rendered luminous, and then examined by means of the spectroscope, it will be found that the light it emits is mainly confined to a small portion of the spectrum just below G. A small amount of yellow-green, yellow, and red, is also emitted, but it is too weak to impress itself upon a sensitive plate.

For all photographic purposes, the light from the tablet may be practically regarded as monochromatic, and its position in the spectrum almost coincides with that which produces the maximum effect upon bromide of silver. Its value, therefore, in measuring the rapidity of a gelatino-bromide plate is considerable. When we take into consideration, however, other salts of silver, the maxima of

which differ very much from that of the bromide, it is pretty plain that the sensitometer cannot give us a comparative test of their various rapidities. It has been estimated by Captain Abney that if a wet plate be exposed beneath a sensitometer depending on a luminous tablet for its light, the number given would really represent only about one-fourth of its real rapidity. The number given on a chloride plate would represent only about one-third of the true value. When iodide is present in a plate, there must necessarily be some difference between the rapidity of such a plate, and one containing pure bromide only, giving the same number in the sensitometer; but the percentage of iodide that is put into an emulsion is usually so small that the slight difference may be disregarded. In such a case, however, the plate containing the iodide has the advantage of whatever difference exists.

Actinometers depending on the action of light on a phosphorescent tablet have not the same great value that the sensitometer has. In this case, we have to consider what rays have the greatest effect upon a tablet. These are undoubtedly the ultra-violet rays, which do not have as much effect upon a gelatino-bromide plate as the dark-blue portion of the spectrum.

An important application of the phosphorescence of substances was made many years ago in the examination of the infra-red portion of the spectrum. It is well-known that the luminosity of the phosphorescent tablets is increased by the application of heat, but the luminosity lasts for a much shorter time. The application of a cold body, on the other hand, decreases the luminosity, but such luminosity extends over a longer period. Hence may be mentioned, by the way, the importance of allowing an interval of time to elapse between exciting the sensitometer

tablet and exposing the plate, thus averaging the luminosity of the tablet which forms the standard light. The red and infra-red (or dark rays, as they are sometimes called) produce the same effect as the more direct application of heat. When a phosphorescent substance that has been rendered luminous is placed in the spectrum, the rays of low refrangibility cause it to become more luminous for a time, but, as the increase in luminosity is but temporary, the lower portion of the spectrum soon appears dark on a bright background.

As far back as 1866, Edmund Becquerel was thus able to show some of the solar lines in the infra-red. More recently, Henri Becquerel has been making further experiments in this direction.

This way of investigating the less refrangible portion of the spectrum is not so good as the photographic method, the lines not appearing as sharp, and the action not extending so low down in the spectrum. The results are evanescent, but by placing the phosphorescent surface in contact with a gelatine plate, a permanent record may be obtained.

CHAPTER X.

PHOTOGRAPHY IN NATURAL COLOURS.

IN a series of articles on the spectroscope, to make no mention of the subject of photography in natural colours would be a grave omission, for spectroscopy has played an important part in the investigation of what little has been done in this direction. The writer does not profess to add anything new in this direction, but it may not be amiss to re-state, in as clear and simple a manner as the subject will allow, what has already been said and done.

There are several ways in which this question is regarded in the photographic world generally, extreme opinions being adopted, as on most debateable subjects. One view is that taken by the optimist, who hopes that the time will come when he can get a photograph in the colours of nature with all the ease with which he manipulates a dry plate and takes a silver print. Another view, quite an antagonistic one, is that the idea is altogether the dream of a visionary, and that its realization is out of the question. Most photographers, perhaps, take a view midway between these two, and while regarding the discovery of what may

be called "the philosopher's stone" of photography as by no means unlikely in the very distant future, do not expect that the "transmutation of the baser metals into gold"—as the transition of black and white to natural colours may be likened to—is to be obtained without some trouble on their part. Such a view is a perfectly reasonable one. Separating the true from the false, the genuine work of the patient experimenter from the quackery of the mountebanks who bring the subject into disrepute, enough has already been done to forbid us to entertain the notion that the seeker after photography in the colours of nature is pursuing an *igneus fatuus*. On the other hand, what little success has already been achieved, and the pains with which that little success has been obtained, only serve to make clearer the immensity of the task.

Experiments have been made in two distinct directions : 1st. In obtaining a picture by a direct process ; 2nd. By taking into consideration the three-coloured pigment-theory of the artist.

In connection with the first of these methods the names of Edmond Becquerel and Niépce de St. Victor are most prominent. Both these investigators, and others who have worked in the same direction, have taken as their basis the sub-haloid salts of silver, the subchloride producing the best results. The method preferred by Becquerel, of producing the subchloride of silver, was to take a silver plate and immerse it, facing a similar plate of platinum, in a bath of hydrochloric acid. By attaching the silver plate to the negative pole of a battery, and the platinum plate to the positive pole, a film of sub-chloride of silver was formed on the silver plate. By placing this plate in the camera of the spectroscope and allowing a brilliant spectrum to fall upon it, the colours of the spectrum were impressed.

Niepcé de St. Victor photographed some dolls dressed in coloured cloths, by this method, using, of course, a very bright light, and giving a very long exposure.

Various other methods have been used to obtain the sub-chloride of silver, amongst others being the plan of immersing a silver plate in a solution of chloride of iron, copper, or calcium. If silver chloride be formed on paper, or films be prepared of chloride of silver emulsified in collodion or gelatine, and these films be then exposed to white light till they become lavender grey in colour by the production of the sub-chloride, they will receive the colours of the spectrum upon them.

Two explanations have been put forward to account for the colours of such images : 1st. That they are due to different stages of oxidation of the silver salt ; 2nd. That they are due to interference of light, as in the beautiful display of colour from soap bubbles, the thickness of particles forming the film determining the colour. Probably both explanations are correct, the second being the outcome of the first. Unhappily, all attempts to fix these photographs have failed. They may be kept for a long time in the dark, and may be examined from time to time in a weak light, but exposure to a strong light blackens the film and obliterates the image.

So far as actual results are concerned, the method about to be described has, so far, turned out most successful. Three investigators thought out the process simultaneously, but only one of them—Ducos du Hauron—had put his thoughts into practical shape. The method depends, as already stated, on the painter's three-colour pigment theory and practice. Three monochromes—red, yellow, and blue—printed on carbon tissue, are superposed. Husnik suggested an improvement on the process by

substituting mechanical printing for carbon printing, thus rendering the necessary registration easier of accomplishment, in addition to simplifying the operations. This was carried out successfully by Albert, of Munich. The negatives were obtained by taking three photographs through green, blue, and red glass respectively; but it must not be imagined that this has any relation to the three-colour sensation theory of Young, Helmholtz, and Maxwell. When an ordinary photograph is taken, a negative is first obtained, from which the print is got. In obtaining a negative for printing in colour, not only must it be a negative so far as light and shade are concerned, but it must be a negative in colour also. For instance, if a negative were obtained through glass that only let through red rays, objects of a red colour would appear black, and objects reflecting no red light would come out white. If this negative were used for obtaining a print on red carbon tissue, those parts of the print which were beneath the black portions of the negative would come out white, instead of red, exactly the reverse of what was required. To obtain a negative for printing the red monochrome, glass of the complementary must be in front of the lens or the plate.

In Ducos du Hauron's process, therefore, the negative for printing the red monochrome was obtained through green glass, the yellow through violet glass, and the blue through orange glass. In fact, as we do not meet either with pigments or transparent media that reflect or transmit light of one wave-length only, to obtain a perfect result, the transparent medium used for making a negative should transmit all rays except those reflected from the pigment in which that particular negative is to print. The whites of the view or painting photographed would appear black in

CHAPTER XI.

THE DIFFRACTION SPECTRUM.

HITHERTO we have only considered the spectrum produced by refraction—that is, the effect produced by a narrow beam of light passing through a prism, the rays being more or less bent out of their course according to their wave-lengths. In Chapter III. it was stated, however, that this was not the only method of obtaining a spectrum. The other method depends on what is known as “interference.”

If two stones be dropped into a pool of water, each one gives rise to a series of waves propagated in all directions. It will be noticed that when the two circles meet, where the summits of the two sets of waves coincide, they reinforce one another. On the other hand, where the summit of one wave coincides with the depression of another wave, there is comparative quiescence ; the particles of water at that place are being acted on by two forces working in opposite directions, their resultant depending, therefore, on their difference. This “interference” is to be met with in all kinds of wave motion—in sound, for instance, where the interference of the waves gives rise to what are known

each negative, and would consequently appear white in each monochrome, and therefore in the three monochromes superposed.

It is many years now since this method was described and put in practice. The most serious difficulties encountered were in photographing through red and green glass. So many improvements have been made since then, the methods of photographing any part of the spectrum by means of dyed films, and the greater facility in photographing the red, either by collodion or gelatine emulsion, that it is about time we heard something more of this process than we do. It is a most ingenious method of obtaining colour-photographs, and might be largely applied.

So far as obtaining photographs in natural colours by a direct method is concerned, we are at present far from its accomplishment, but it is in this direction, most probably, that we must look. It opens up a large question. When an image, capable of fixation, is obtained in natural colours by a comparatively short exposure, our difficulties, perhaps, will only have begun. The proper representation of light and shade, detail in the shadows, &c., are matters that at the present time require constant attention on the part of the photographer. Who knows but what, when colour-photography seems within our grasp, strictly analogous questions will come to the fore with fifty-fold complications that the representation of colour must inevitably bring?

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as "beats" in music. A similar phenomenon takes place when light waves strike a thin film, such as a soap-bubble. Some of the waves are reflected from the surface of the film ; others penetrate the outside of the film, but are reflected from the inner surface ; if one such wave emerges half a wave-length behind the other, the two waves mutually destroy one another. But as a ray of white light is made up of a number of ethereal vibrations of different wave-length, a film whose thickness is suitable for producing interference with one set of vibrations will not produce interference with vibrations of a different wave-length ; some vibrations, therefore, destroy one another, and by their absence from the rays which finally reach the eye, give rise to colour.

Again, if a series of waves—such, for instance, as may be set up in a pool of water—meet with an obstacle, a new series of waves is set up at that point. Hence the facility with which water or sound waves turn a corner. Light, however, is usually regarded as travelling only in straight lines, and it was this general experience that was the great obstacle to the acceptance of the wave theory of light. Newton contended that if light was due to wave motion, the waves should bend round opaque bodies, and produce the motion of light behind them, just as waves of water wash round a rock. It has since been shown that this does actually take place, but the amount of interference is so great as to render it unnoticeable except under favourable conditions.

The "diffraction" or bending round of light-waves can be shown in a number of ways, but it is proposed here to give only a few simple experiments which can easily be performed by the photographer in his darkened room, and which will readily demonstrate the action of the diffraction gratings used by spectroscopists.

Take a piece of tinfoil, and, with thin gum or gelatine, attach it to a piece of glass. Now draw a sharp knife across a portion of it ; this will give a fine slit. Place a lighted candle at one end of the room, and, retiring to a distance of four or five yards, hold the tinfoil in front of the eye, with the slit perpendicular, covering the slit also with a piece of red or ruby glass. The flame of the candle, appearing of course red, will be seen considerably broadened out, and at each side of it a series of bands of red separated by intervals of darkness. Now replace the red glass by a piece of blue; the blue bands will appear narrower and closer together than did the red. If no coloured glass be used, a series of spectra appear, the blue ends appearing nearest the central flame.

If the room is a very small one, it is advisable to place a slit in front of the candle also. This slit need not be narrower than one-sixteenth of an inch for observations at about two feet distance. Or, again, a piece of tinfoil may be fixed on the glass of the dark-room lantern, and a fine slit be made with a sharp penknife ; observations through the other slit may then be made at a few inches distance.

For an explanation of what takes place, let us consider theoretically what should be the result of the interposition of an obstructive body in the path of the waves.

In the accompanying diagram we have a series of waves coming from a luminous point in the line B A produced. The summits of the waves are represented by continuous lines, and the depressions by dotted lines. Where the diffracting body C comes in, we have another series of waves sent up, meeting the original waves. At points marked O, where a continuous and a dotted line meet, we have two waves of conflicting phase tending to mutually annul one another. At the points marked X, where the

waves are in the same phase, they strengthen one another, producing alternate spaces of light and darkness.

This is a simple case. In the experiment detailed, we have two such diffracting bodies, viz., the two edges of our slit, giving us a series of light and dark spaces on each side

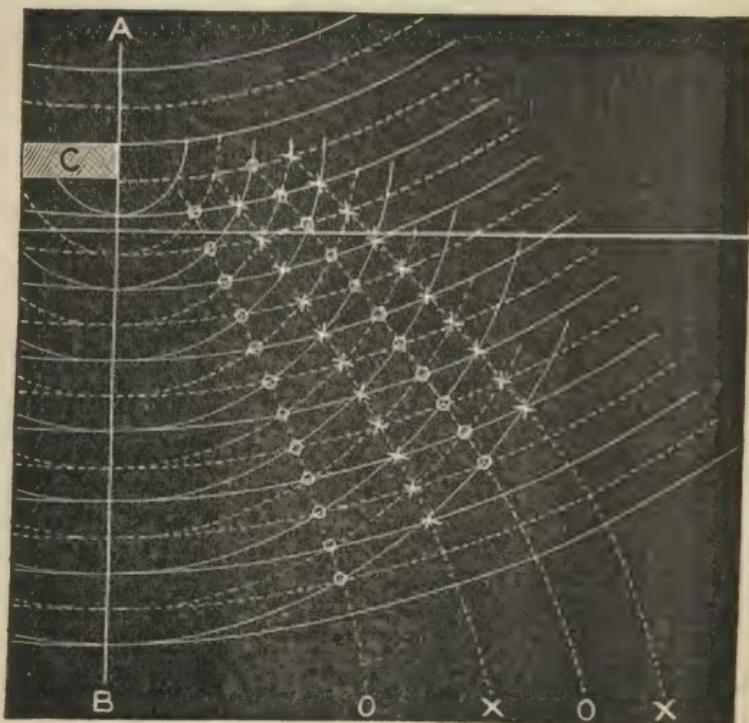


Fig. 13.

of the bright space in the centre. By somewhat complicated diagrams, it could be shown that the distance apart of the two edges of the slit would have an important effect on the appearance of the diffraction images. This effect can be best shown by a simple experiment similar to that already detailed.

Take the piece of tinfoil on glass, and cut with a sharp penknife a slit of gradually increasing width—that is,

slightly wedge-shaped. On looking at the candle through different parts of this slit, it will be noticed that the wider the slit the narrower the spectra appear, and the closer together are they.

In the diffraction grating we have not one slit only, but a series. A number of fine lines are ruled by means of a diamond upon glass or speculum metal, at equal distances apart, this being regulated by a screw. Gratings containing as many as three thousand lines to the inch have been produced by photography; but this is far below the number that can be got into that space by mechanical methods. The lines, whether produced by photography or by the diamond, and if by the latter, whether on glass or on a reflecting surface, act as so many opaque edges to set up secondary waves, which, by meeting the original waves which pass through, are reflected from the intermediate spaces, and produce a series of spectra. If the lines are far apart, the dispersion is small; if close together, the dispersion is considerable, as in the experiment with the wedge-shaped slit. Whatever be the number of lines to the inch, it is of the greatest importance that the distances apart of the lines should be regulated to a nicety, or errors must come in.

The greatest advantage that the grating possesses over the prism lies is the fact that the wave length of any particular line is easily determined by it. It is only necessary to know the distance between the scratches and the angle between the axes of the collimator and the observing telescope, and the wave-length may be obtained by a simple calculation.*

* $\sin \delta = \frac{n\lambda}{d}$ where δ = observed angle

n = order of the spectrum

d = distance between scratches

λ = wave length.

The grating is becoming of more importance than ever since Professor Rowland introduced his grating ruled on spherical surfaces. For photographic purpose no lenses whatever are required with them, and steps are being taken to bring them within the reach of those who may require them. At present, however, the demand is greater than the supply. There is no reason why, before long, the photographer should not be able to get a very efficient spectroscope for a very small outlay. In the next and concluding article, therefore, when reference will be made to the use of photography in spectroscopy, a brief description will be given of the simple mechanical arrangements that render the Rowland grating so easy of manipulation.

CHAPTER XII.

AFFILIATION OF PHOTOGRAPHY TO SPECTROSCOPY.

THE aid which photography has given to the work of the spectroscopist pure and simple has been great; but to give it in detail would be beyond the limits of a series of articles written for photographers. In considering this subject, therefore, it is advisable to consider, mainly, the methods which the spectroscopist has adopted, more than the results he has arrived at. The subject may conveniently be divided into two parts—1st. Solar and chemical work, which are too closely connected to be treated as separate subjects; and 2nd. Stellar spectroscopy.

When the chemist has recourse to the spectroscope in a purely analytical examination of some compound, or mixture of compounds, there is no real necessity for photography to be brought in at all. The elements are recognized by their most important lines which the chemist is in the habit of observing, and even when some unlooked-for line is noticed, the eye observation and measurement are relied on as affording the quickest and readiest means

of determining its cause. In advanced research, however, when it is desired to notice the molecular nature of the substance under examination, photography has proved a valuable auxiliary, more especially in recording what takes place in parts of the spectrum that the eye is not able to take cognizance of. And when, again, the source of light is too weak for eye observations to be definitely made, photography, by its power of accumulating impressions, as it were, has done a great service; for instance, in examining faint flames, or in resolving the comparatively faint light given by the electric spark in highly rarified media. In such cases, however, the simple method of procedure is to obtain as high a dispersion, either by prisms, or by the diffraction grating, as may be found necessary, and to direct the spectroscope to the source of light, and insert a plate in the camera attached to the instrument.

But when examining the light from the sun, it is found that so innumerable are the number of lines in the spectrum, and so greatly does that number increase when a higher power is brought to bear upon them, that eye observations are too tedious, and many lines are found to be overlooked. One has only to refer to the celebrated map produced by Dr. C. W. Vogel, of the Potsdam Observatory, and to compare it with the celebrated map produced by Angström by eye observations only, to see how great an advance the former is upon the latter. A few figures bearing on the subject may not be without interest. In a portion of the blue near G, a region accessible to both the eye and the plate, but more so to the latter, Angström measured 94 lines, Rutherford photographed 275 lines, and Lockyer photographed 412. In regions which are only just within the ken of the eye, the

reader need scarcely be told that the superiority of the photographic record is still more marked. In solar work, when the behaviour of some particular line or lines is in any way remarkable—and this is frequently the case—it becomes absolutely necessary to ascertain what element the line or lines in question belong to. It is for such work that careful and elaborate mapping of the lines of all the metallic and non-metallic substances known here is most desirable, and for this work the photographic plate is most in request, except in recording the lines in such portions of the spectrum—such as the green and yellow—that lend themselves most readily for eye observation. At present we have chiefly to rely on the work of Kirchoff, Angström, and Thalèn, for the coincidences of terrestrial spectra with dark solar lines. These workers did not make use of photography, and it is worthy of note that the first-named lost the use of one of his eyes in compiling the laborious piece of work that established the existence of

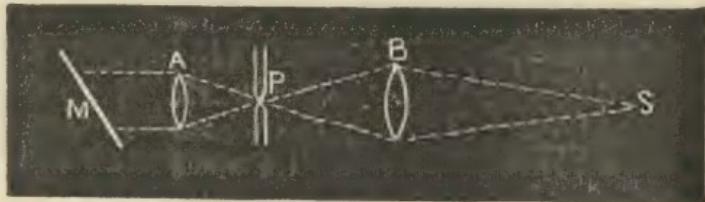


Fig. 14.

many terrestrial substances in the sun. Some time since, Lockyer commenced mapping the metallic spectra on an extended scale, but only a very small portion of it has as yet been published. The foregoing diagram will explain his method of working.

The sun's rays are thrown by means of the mirror M, driven by clockwork, on to a lens A, which forms an image of the sun between the carbon poles, P, of the electric arc. A second lens, B, throws the image of the

sun, and also of the carbon points, on to the slit, S, of the spectroscope. By this means the light of the sun, and also that of the metal placed on the poles, come from the same point before entering the instrument. The slit of the spectroscope has an arrangement for opening only one-half of the slit at a time, so that first the arc and then the sun, or *vice-versâ*, are impressed on the plate, one appearing above the other. A little consideration of the conditions of working will show that the coincidences of metallic and solar lines cannot fail to be very precise.

The best map until very recently of the ultra-violet portion of the spectrum that has been produced is that by Cornu, and Professor Hartley has been assiduously mapping the metallic lines in that region. Professor Rowland has lately, by means of his beautiful gratings, produced a magnificent map of the solar spectrum by means of photography, and by drawing a scale of wave-lengths on the original negatives, the whole can be reproduced by photo-mechanical methods without the intermediation of the draughtsman. The mechanical arrangement adopted by Professor Rowland in using his curved gratings, in which the focus is obtained automatically by means of trammels, is shown in the sketch on page 73.

A A is a board with a groove, *a a*, along its centre. At the point where the slit S is fixed, another board, B B, is joined on at right angles. This board has a similar groove, *b b*, the position of the slit being opposite the centre of the groove. C C is a board carrying the grating G, and the ground-glass or photographic plate P, the distance of the two apart being exactly equal to the radius of curvature of the speculum on which the grating is ruled. At points exactly beneath the centre of grating and plate, the board C C is fixed by means of a single screw on to

pieces of wood, *c c*, and *d d*, that slide along the grooves. In whatever position the board *C C* is placed, the plate is always in focus. Of course it is necessary to keep out extraneous light by covering the whole arrangement, or

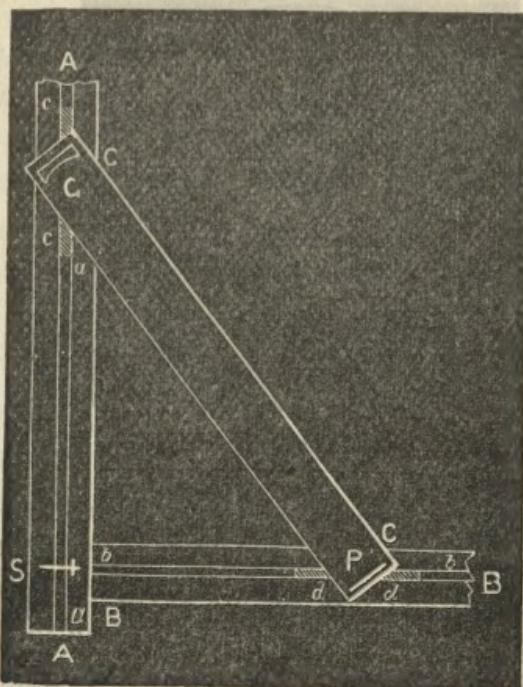


Fig. 15.

using long bellows or boxes open at both ends. Photographers will probably find this the most convenient arrangement, but there is another method shown diagrammatically on the following page.

From the centre *C* a circle is drawn with a radius equal to half the radius of curvature of the speculum. The grating *G*, the slit *S*, and the plate *P*, may be placed at any part of this circle, and the plate will always be in focus for whatever part of the spectrum may be at that place; of course the slit must always be directed towards the grating, and the plate be tangential to the circle. It can be stated from

the writer's personal knowledge that this method has been adopted by at least one eminent spectroscopist in America, and another in England.

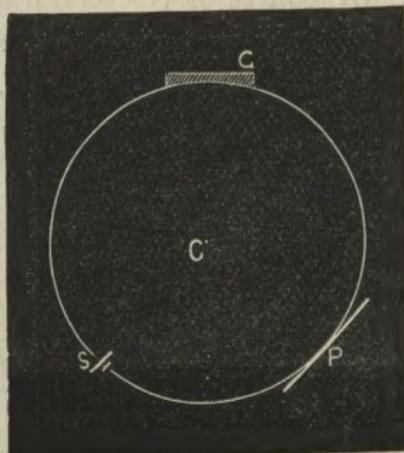


Fig. 16.

In photographing the spectra of stars, planets, nebulæ, &c., the difficulty to be overcome is the feebleness of the light when it is spread out in the form of a band. Dr. Huggins, the principal worker in this direction, uses the reflecting form of telescope, and focusses the image of the object upon the slit of spectroscope, and throughout the long time of exposure has to carefully keep it there, it being practically an impossibility to get the clock of the telescope so accurately adjusted as to follow the motion of a star with unfailing accuracy. The spectroscope has lenses of quartz and a prism of Iceland spar, both these substances being highly transparent to the ultra violet rays. The minute, but sharp and beautiful spectra which Dr. Huggins has been able to produce of the light from some of the stars and nebulæ, and of those occasional celestial visitors, the comets, testify to the usefulness of photography, and more especially modern rapid dry plates,

in this delicate research. On the other side of the Atlantic, too, the late Dr. Draper has done useful work in this direction. The evidence, too, which Dr. Draper obtained of the probability of the existence of oxygen in the sun is yet another valuable outcome of photo-spectroscopic research.

Nor must mention be omitted of the work of Captain Abney in examining that invisible portion of the spectrum which lies beyond the red, and his work in conjunction with Colonel Festing in investigating the absorption spectra of organic compounds, and establishing evidence of the existence of hydrocarbons between the earth and the sun. Without photography, such research would have been impossible.

Amongst the more recent work in photospectroscopy may be briefly mentioned the attempts made to determine the constitution of the solar corona. From eclipse to eclipse, eye observers were able to determine little or nothing of the character of the light upon the corona. Very few bright lines had been seen in it, and only the most important line had had its position determined with accuracy.

The positions of thirty lines have now been determined, and, to quote the 1882 eclipse report, which has just been published, "If any doubt previously existed respecting the presence of dark lines in the corona spectrum, that doubt is now completely removed."

And here these chapters must conclude. They profess to be little more than a sketch, and there have necessarily been many omissions, but, it is trusted, not important ones. The writer has found much pleasure in penning them, and he trusts they may be of some little avail in assisting photographers to realize the close connection that exists between

their daily practice and its scientific principles, and the necessity for the complete understanding of both, on the part of those who would be complete masters of their work.

